5G

Technology overview and Architecture

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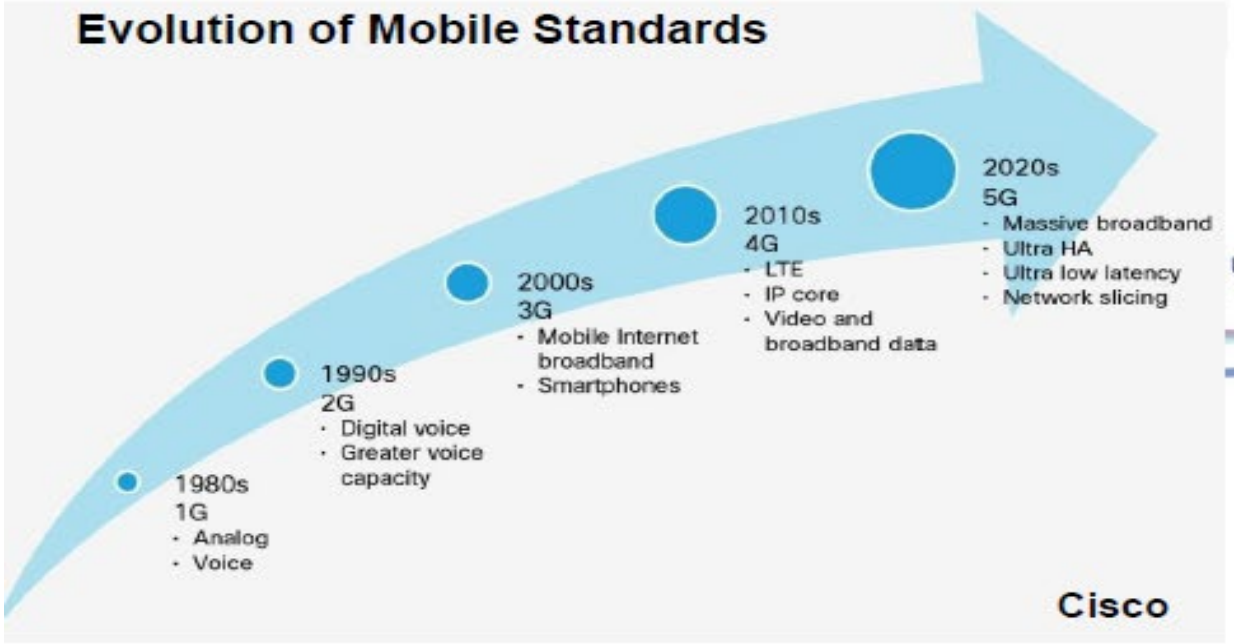
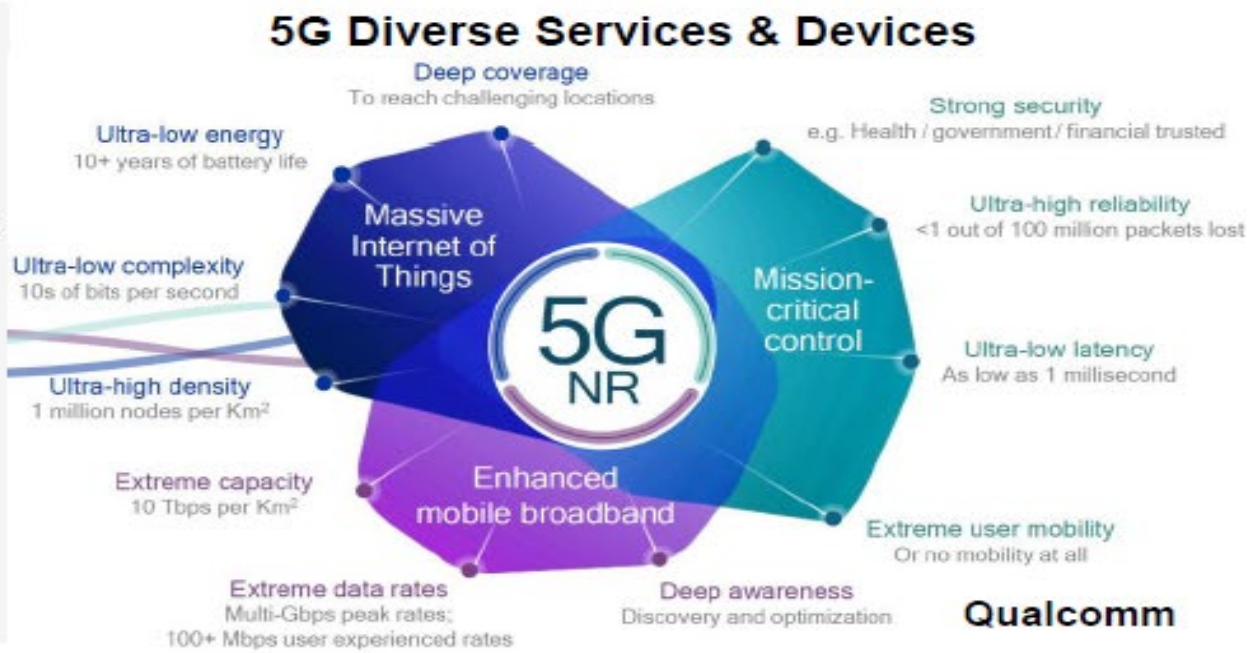
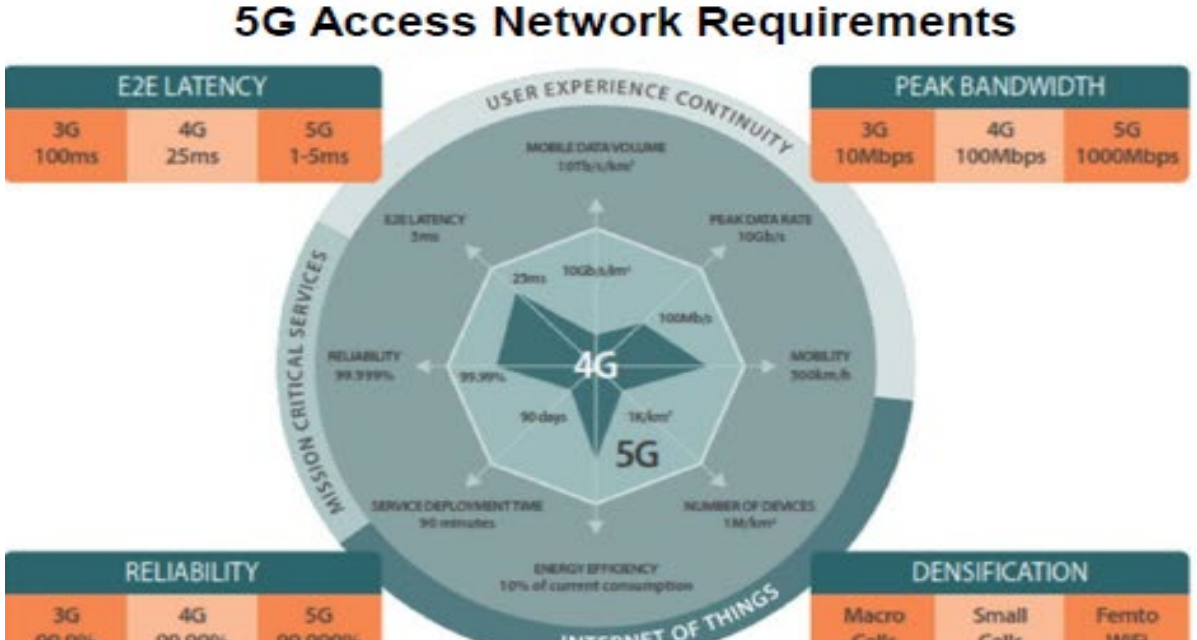
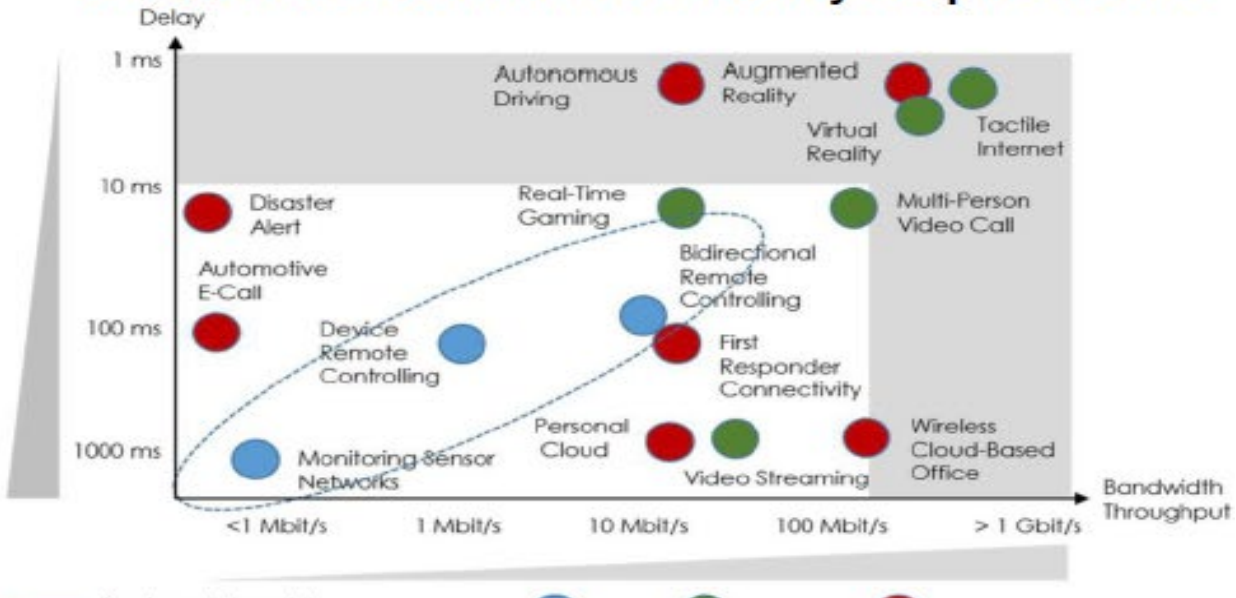
Cellular 2G, 3G, 4G & 5G protocols &Apps Evolution









What is New?

- Unlike previous generations the 5G network will be not just another “G” but more like a “platform for innovations”, network of networks.
- *Non-standalone (NSA)*
- 4G and 5G new Radio (NR) resources are combined. Core Network is either existing 4G EPC or 5G Core (5GC)
- *Standalone (SA)*
- Only one RAN is used 5G NR or LTE and operated alone with the Core.
- *5G Use Cases:*
- Enhanced Mobile Broadband (eMBB): improves mobile data rates, latency, mobility, user density, indoor and outdoor coverage to support broadcasting & streaming.
- Massive Machine Type Communication (mMTC): smart cities, smart metering, remote monitoring, fleet management, logistics, tracking and smart agriculture.
- Mission Critical Machine Type Communications (MC-MTC) or Ultra-reliable low-latency communications (URLLC): very high reliability and availability as well as very low latency for critical communication. Industrial automation, remote surgery, traffic safety, smart grid, emergency services and remote manufacturing.
- Space based networks for Ubiquitous coverage, Mobility & redundancy, Broad cast & multicast.

Space based 5G platforms & use cases

- GEO: cover large specific geographic area ~ 36,000 km above, synchronized, require small low priced stationary directional antennas
- MEO: non-stationary, orbit 5 to 10 hours, 8,000 km to 18,000 km. deployed in large constellations for continuous coverage: GPS
- LEO: altitudes 400 km to 1,500 km. orbit earth every 1.5 to 2 hours. Faster connections
- HAP: 20 km to 40 km. Balloons or airships. Small area coverage & quick to deploy
- High-throughput Satellites (HTS): Tput over 100 Mbps. Lower cost per bit.
- Use cases: Edge Server Connectivity, Fixed Backhaul to Remote Locations, Hybrid Networks, 5G on moving platforms, IoT service continuity.

Wireless Technology & Spectrum Summary

Protocol	Spectrum	Notes
Cellular 2G, 3G, 4G & 5G	850 & 1900 MHz,4G & 5G bands 600, 700, 1700, 2100 & 5200 MHz. 5G auctions 24/28/37/39/47 GHz. 2G 1Mbps, 3G 15Mbps, 4G 50Mbps, 5G 3Gbps	Licensed through FCC
IEEE 802.11 Wi-Fi	Legacy 802.11a/b/g/n to 600 Mbps & 802.11ac to 3.5 Gbps on unlicensed 2.4 & 5GHz	LAN, low cost H/W, 802.11ax provides 10.5Gbps. Efficient spectrum use & increased T-put
IEEE 802.16 WiMAX	2.3/2.5/3.5 GHz use. 802.162 adds MIMO	Last mile broadband to 50 km, limited market adoption to date
Citizens Broadband Radio Service (CBRS)	3550-3700 MHz for shared unlicensed use of 80 MHz band & licensed use with priority of up to seven 10 MHz channels. Shared with US Military Radar, Fixed Satellite systems	Shared spectrum use with dynamic allocation
White Spaces Wireless	IEEE 802.11af (White-Fi). Select unlicensed bands from 470-700 MHz IEEE 802.22	Uses TV White Space Database (geo Database)
Short Haul Special Purpose Networks	Bluetooth IEEE 802.15.1 at unlicensed 2.4GHz to 1Mbps, Zigbee 802.15.4 at unlicensed 915 MHz & 2.4GHz up to 250Kbps	Support health monitoring, smart homes/buildings/cities
Low-Power Wide Area Networks (LPWANs)	NB-IoT	High device volume, high growth opportunity at low data rates/low cost

Goals/Objectives/KPIs, Standards & Specifications

5G KPIs and 3GPP's Timeline Rel 15 in 2018 and Rel 16 in 2020

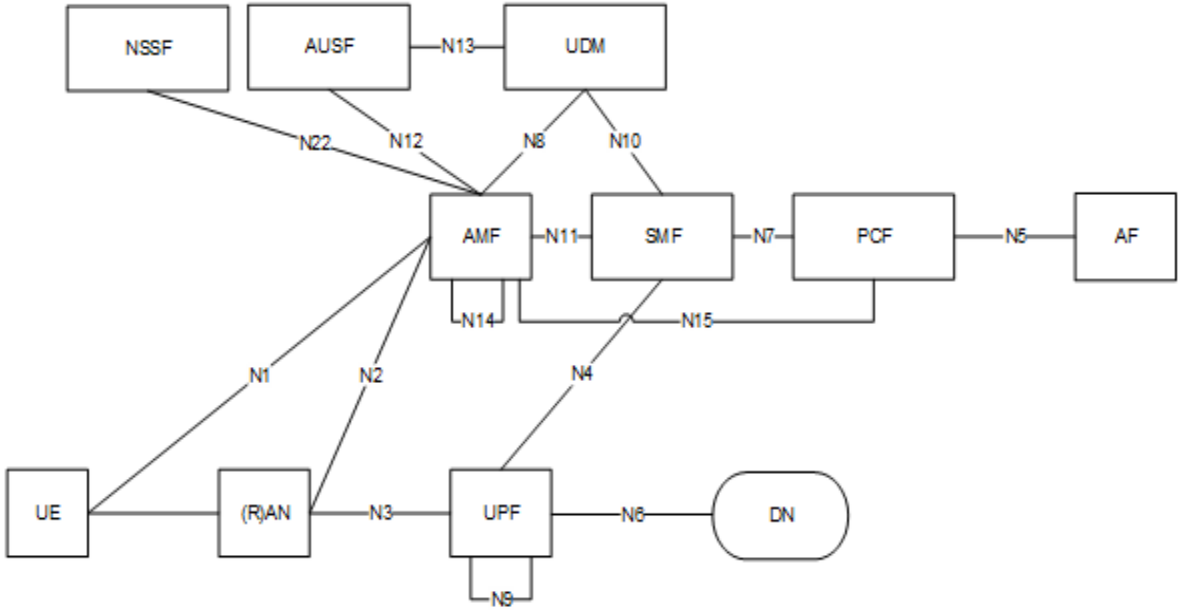
- The International Telecommunication Union (ITU) has put forth some requirements for 5G that focus on fulfilling three key performance indicators (KPIs):
- >10 Gb/s peak data rates for the enhanced mobile broadband (eMBB)
- >1 M/km2 connections for massive machine-type communications (MMTC)
- <1 ms latency for ultra-reliable low-latency communications (URLLC).
- 3gpp.org: Stage 1, 2 and 3 Specifications

- *stage 1 specifications* define the service requirements from the user point of view.
- *stage 2 specifications* define an architecture to support the service requirements.
- *stage 3 specifications* define an implementation of the architecture by specifying protocols in detail.

- OMA (Open Mobile Alliance): openMobileAlliance.org, 3GPP2, ITU, ETSI, IETF, ANSI, NIST, regulating bodies FCC & TIA

5G CN Architecture

- Traditionally 3GPP has documented the architecture of the system (in Stage 2 Working Groups) using Reference Points and Network Functions
- In principle there is one Reference Point between each pair of Network Functions
- The functionality of each Reference Point is then defined in terms of the messages exchanged between the Network Functions, as shown in call flows in the Technical Specifications
- The Stage 3 Working Groups take these call flows and translate them into protocols
- Different protocols can, and often are, used for different Reference Points
- Here is the 5G system architecture depicted in this Reference Point style (from TS 23.501)



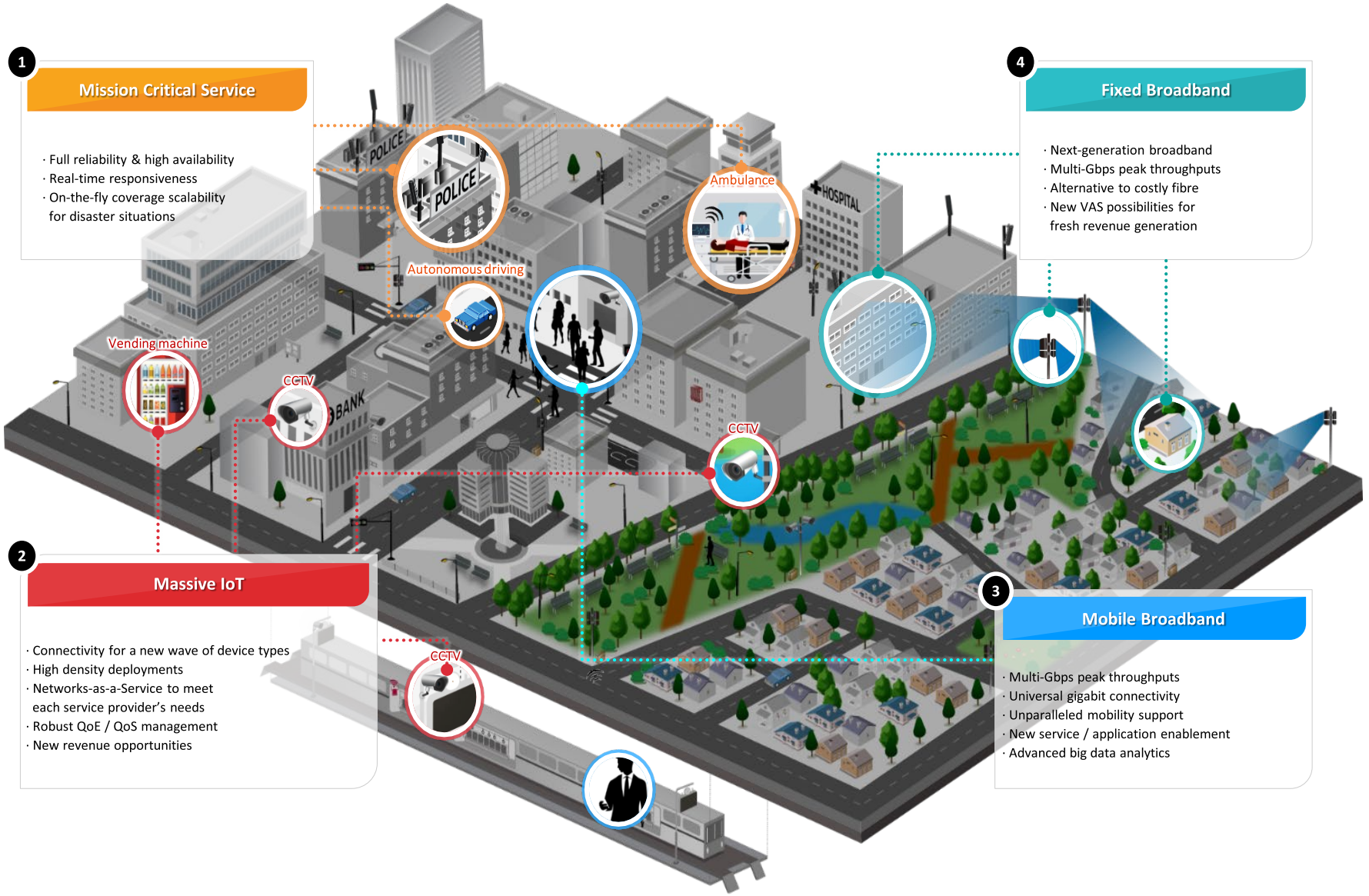
Technology features, services, applications

5G features

- New Radio (NR), Millimeter wave: 1 to 6 GHz is very crowded, 30 to 300 GHz
- Next Generation Core (NGC)
- Small cells/HetNet
- Massive MIMOs
- Beam forming
- NOMA, Non-Orthogonal Multiple Access
- MEC, Mobile Edge Computing
- Full Duplex
- Capacity = Cell Density X Spectral Efficiency X Available Spectrum
- mMTC, massive Machine Type Communications
- eMBB, enhanced Mobile Broad Band
- URLLC, Ultra-reliable and Low Latency Communications (Mission Critical Communications)
- MEC, Multi-Access Edge Computing or Mobile Edge Computing
- Network Slicing
- NVF
- Software Defined Radio (SDN)

- Architecture, Protocols, Interfaces, IEs/Attributes/AVPs, Coding, protocol stack peer to peer communication
- Open Systems vs. Closed Systems: Security Aspects
- Convergence of Networks and Data Centric
- Platform: Mobile vs. Desktop
- Operating Systems:
- Spectral Efficiency, Band Width, Latency, Capacity, Scalability
- Complex & many N/W nodes, Flat IP Architecture, Control plane and User Plane Separation (CUPS)

5G Key Service Scenarios

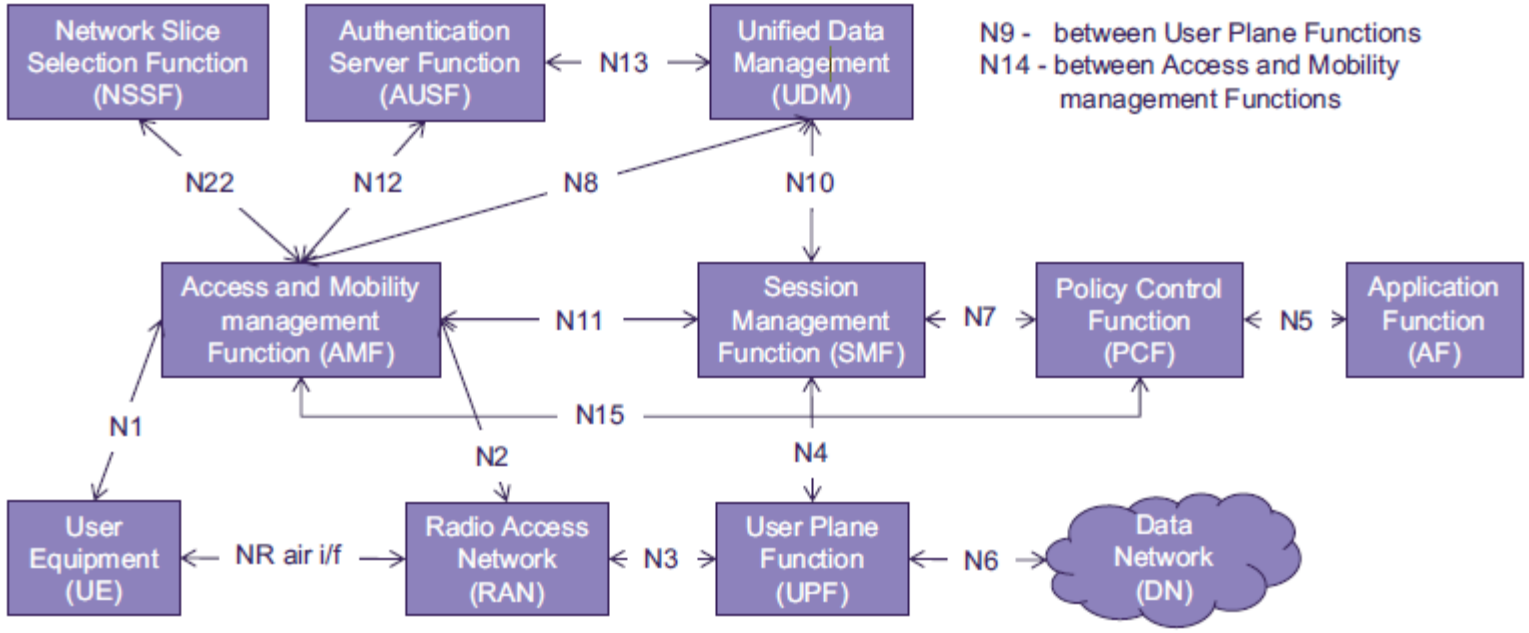


Requirements & Apps

- 10x bandwidth per connection
- Low-ms latency
- Five 9's reliability
- 100% coverage
- >10x connections
- 50Mbps per connection everywhere
- 1000x bandwidth/area
- 10 year battery life
- Reduction in TCO, Total Cost of Ownership
- Connected cars, Industrial handhelds, Asset trackers, health monitors, wearables, security systems, parking systems, sensors, smart city, utility meters, agricultural monitors, IoT gateways, cameras, vending machines, energy management

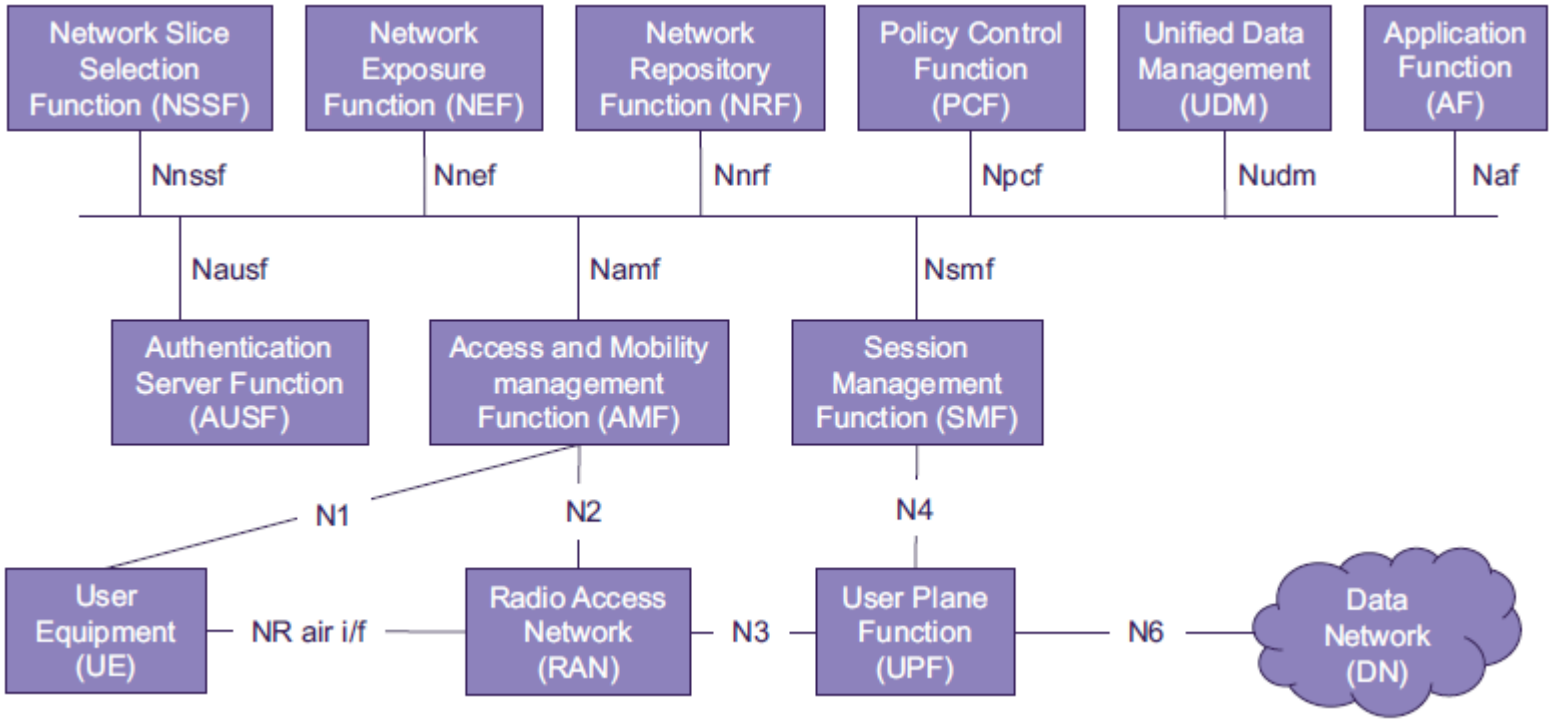
5G Network Architecture

- Control Plane functions: Core Access and Mobility Management function, Session Management function, Policy Control function, Application function and Network Slice Selection function (NSSF)
- Subscriber Management functions: Authentication Server function and Unified Data Management function
- User Plane
- N1 interface: 3GPP non-access stratum between UE and CN



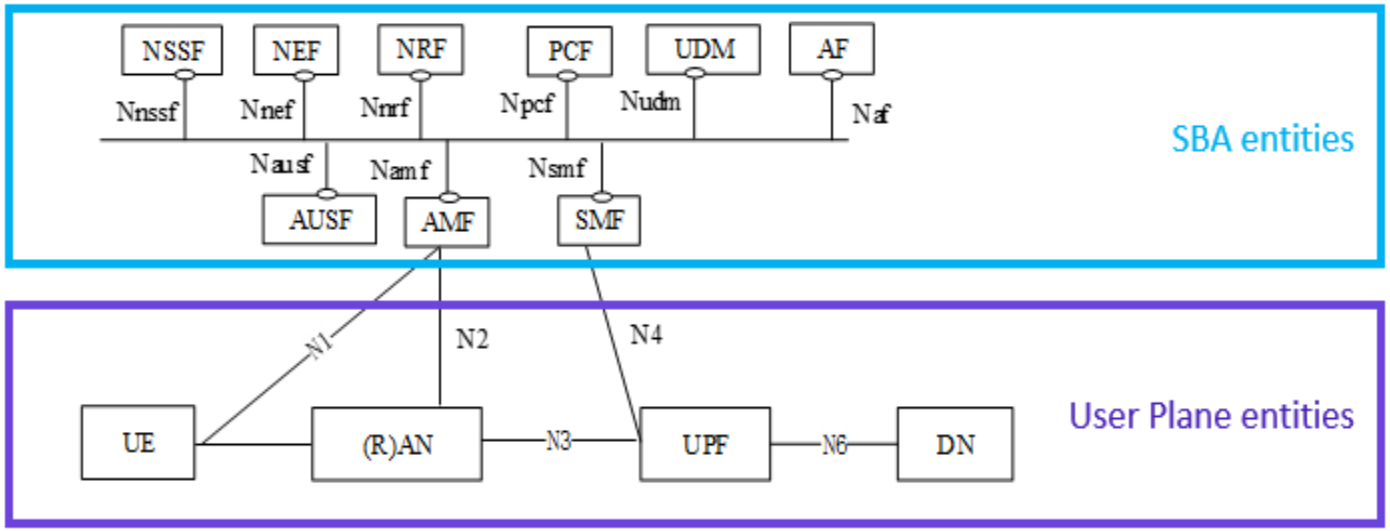
5G Service Based Architecture

- Separate Control plane functions from User plane fns: independent scalability, modularize fns for n/w slicing, evolution and flexible deployment
- Network Repository Function (NRF) and Network Exposure Function (NEF)



CN redefined as Service-Based Architecture (SBA)

- **Here is the 5G system architecture depicted in the SBA style (from TS 23.501)**



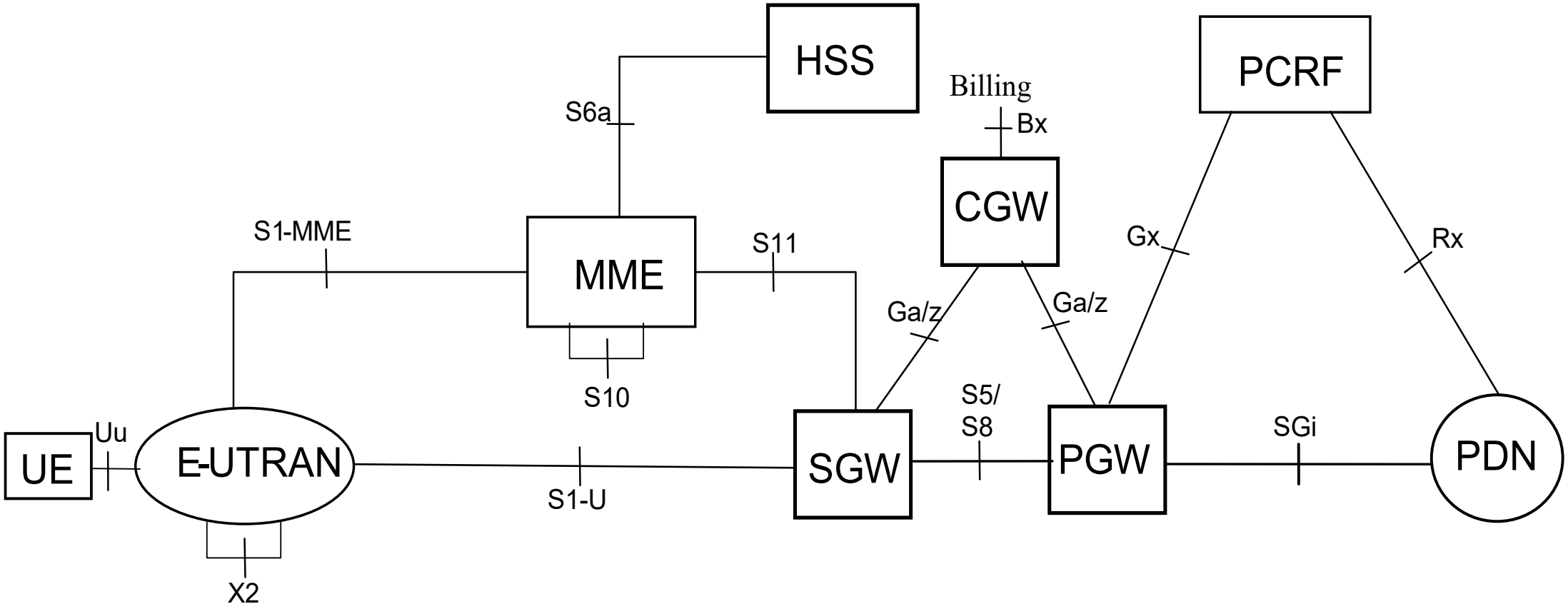
Authentication Server Function (AUSF)
Access and Mobility Management Function (AMF)
Session Management Function (SMF)
Network Slice Selection Function (NSSF)
Network Exposure Function (NEF)
NF Repository Function (NRF)
Policy Control Function (PCF)
Unified Data Management (UDM)
Application Function (AF)

Unified Data Repository (UDR)
Unstructured Data Storage Function (UDSF)
5G-Equipment Identity Register (5G-EIR)
Security Edge Protection Proxy (SEPP)
Network Data Analytics Function (NWDAF)

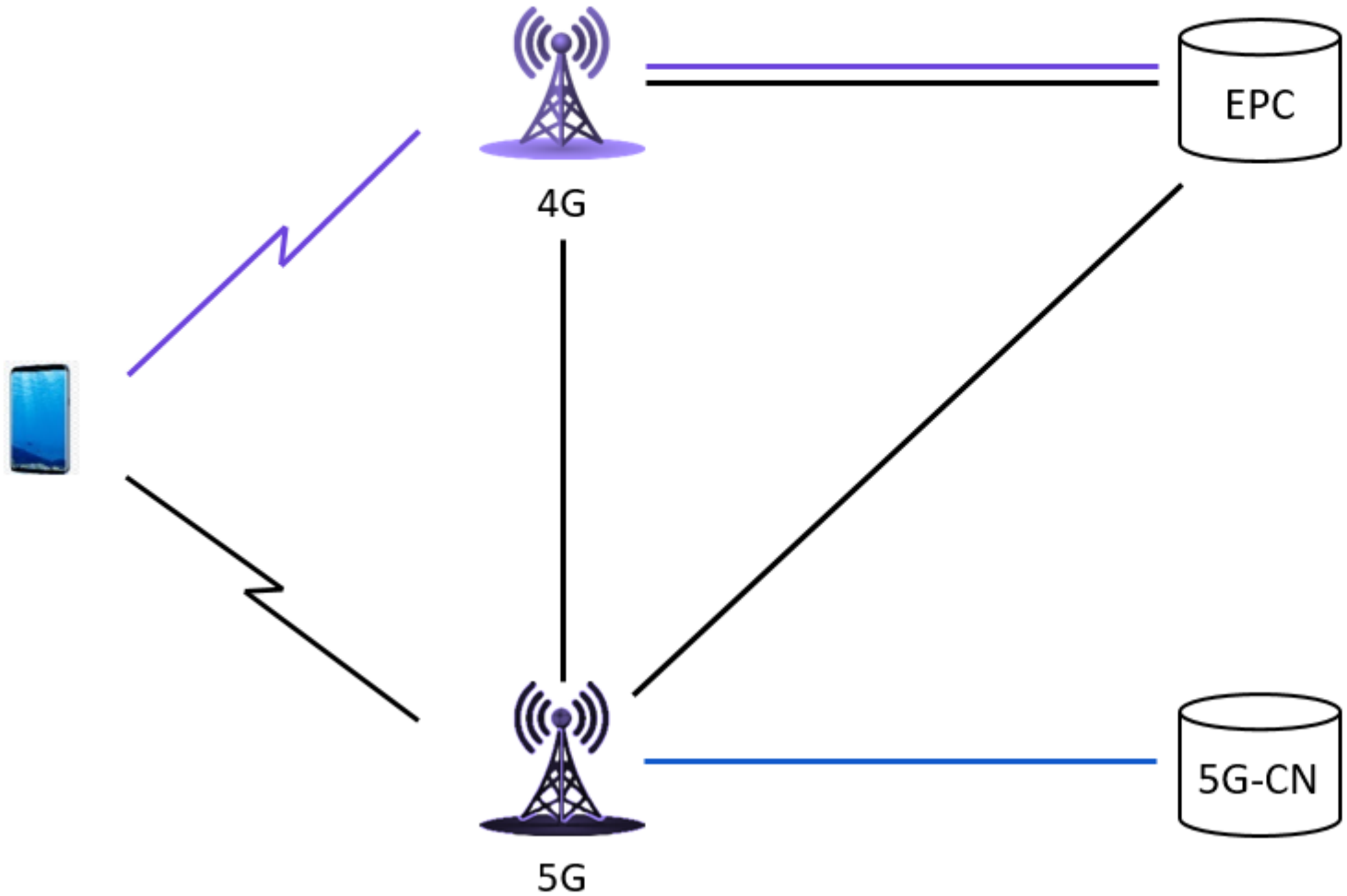
User Plane Function (UPF)
Data Network (DN), e.g. operator services, Internet access or 3rd party services
User Equipment (UE)
(Radio) Access Network ((R)AN)

- **Note that the User Plane functions, and their direct interactions with the Control Plane, are still depicted as Reference Points**
- **However, all of the other Control Plane functions are connected by http2-based service-based interfaces**
- **In principle any service-based interface exposed by a Network Function can be used (consumed) by any other Network Function**

3GPP LTE Reference Architecture



5G – Standalone vs Non-Standalone



Today – 4G Access

Device attaches to LTE/4G radio and Evolved Packet Core (EPC)

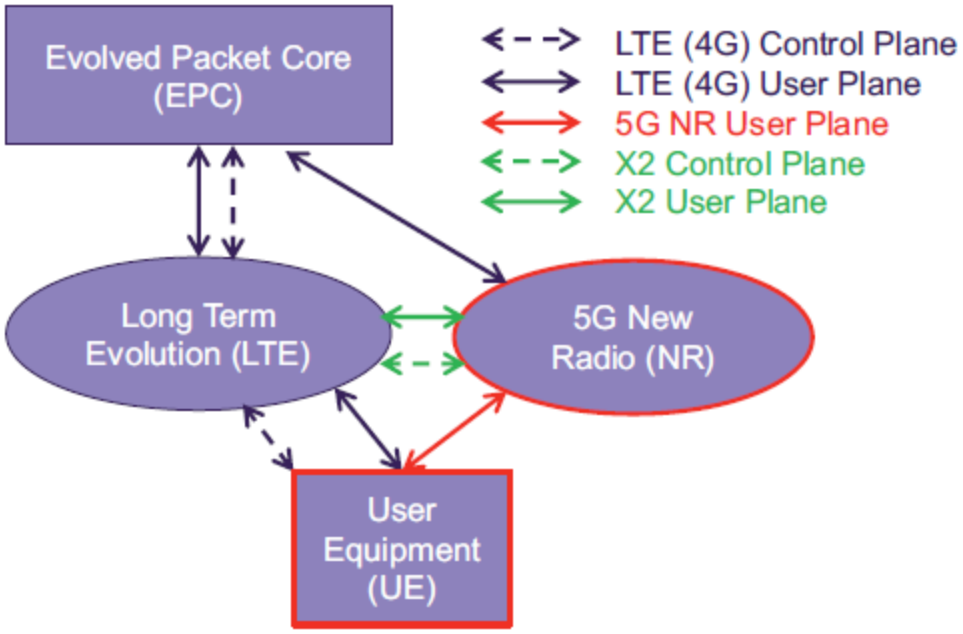
Early 5G – Non-Standalone

Device attaches to 5G-NR, which routes either via 4G Base Station to EPC, or direct to EPC

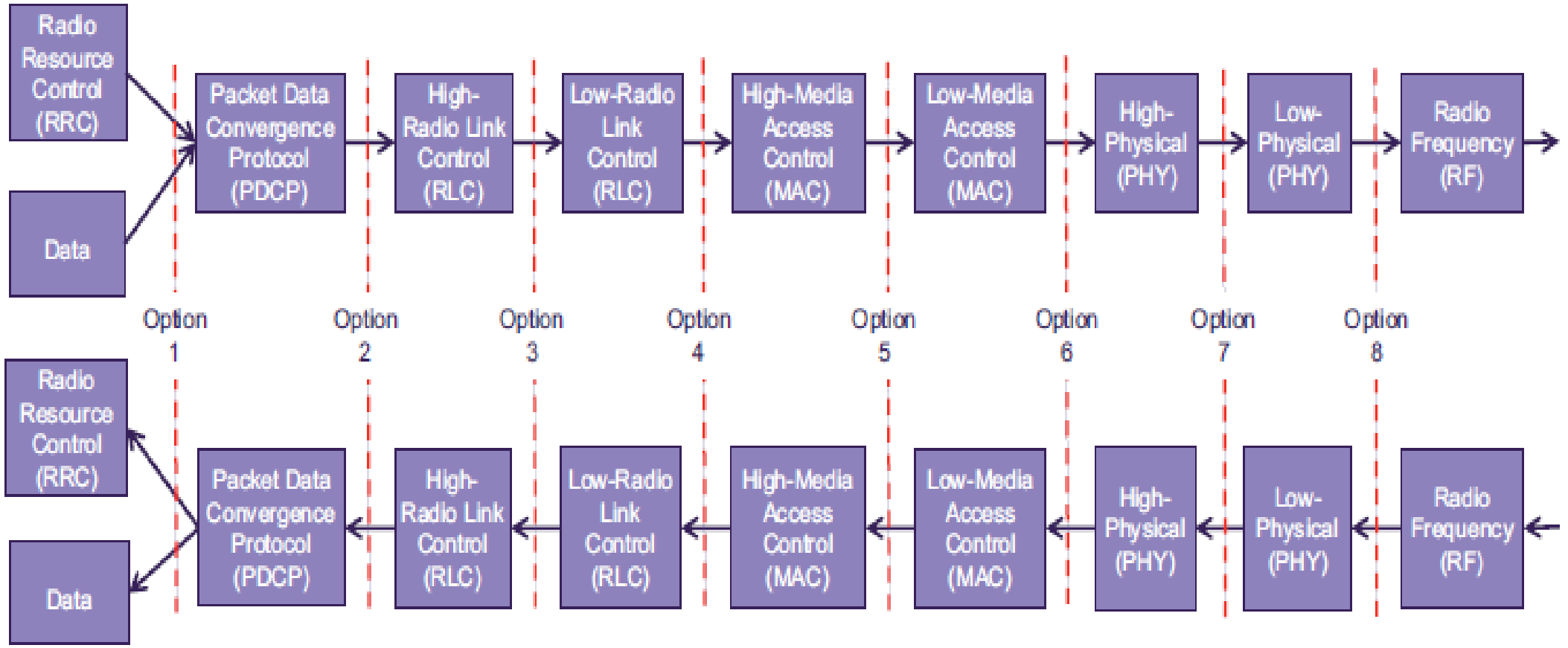
5G Standalone

Device attaches to 5G-NR and 5G Core Network.

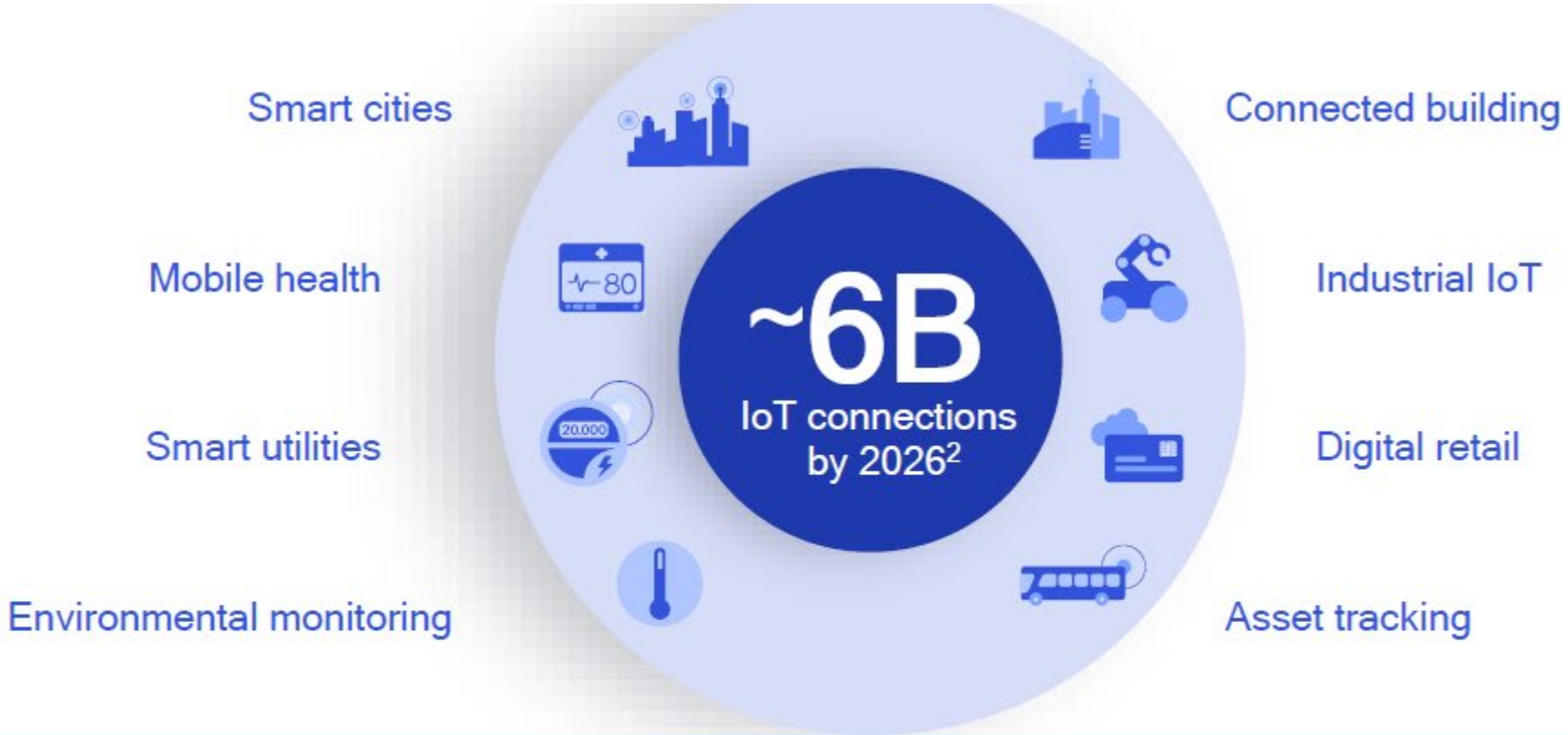
Option 3: 5G non-standalone network architecture



RAN protocol architecture 3GPP TR 38.801



IOT Services enabled by Cellular Technologies, 3GPP and non-3GPP (Wi-Fi, NFC, Bluetooth) Solutions & LPWA[1] use cases



Always-available, ubiquitous connectivity

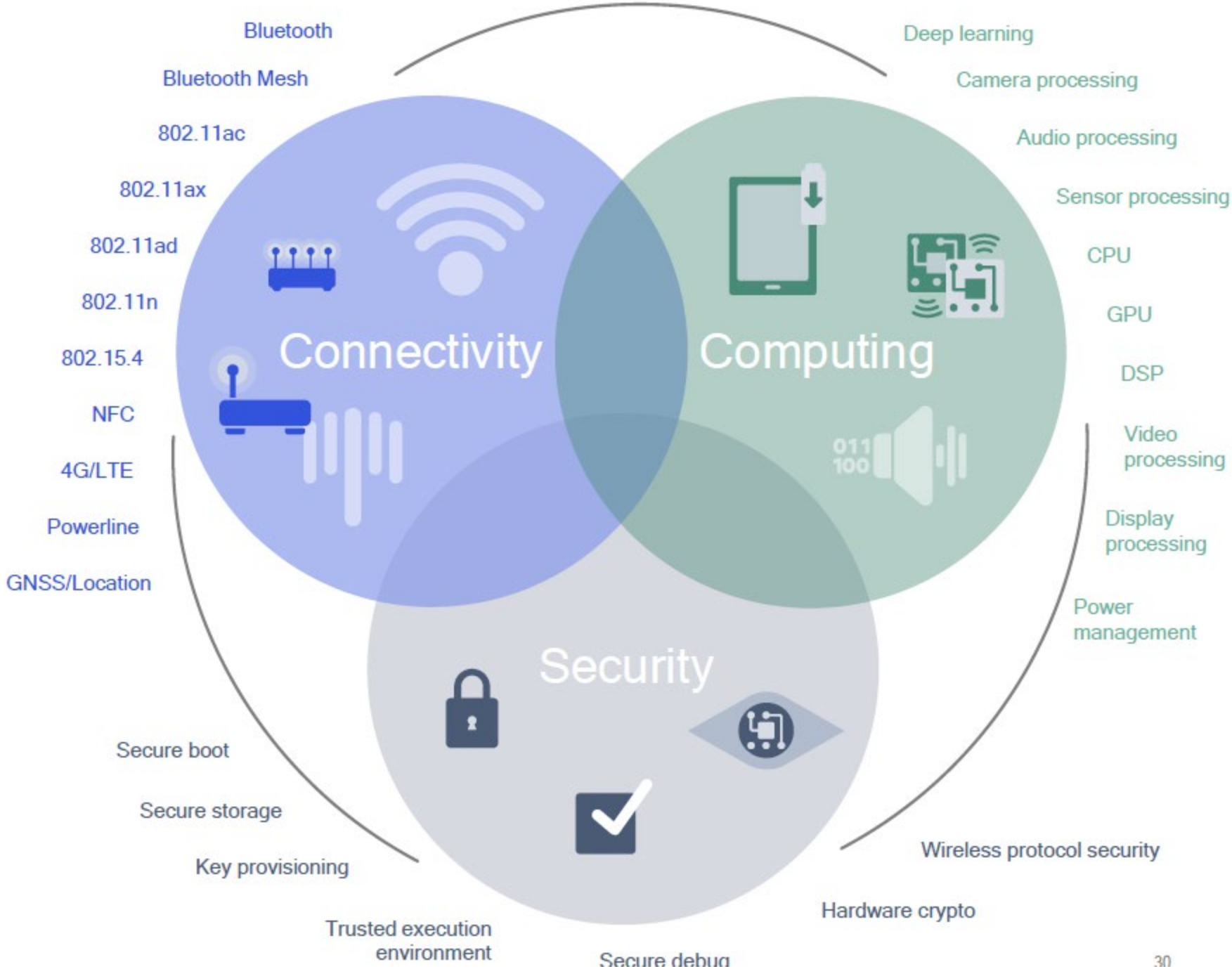
Mature, interoperable global ecosystem

Scalable performance

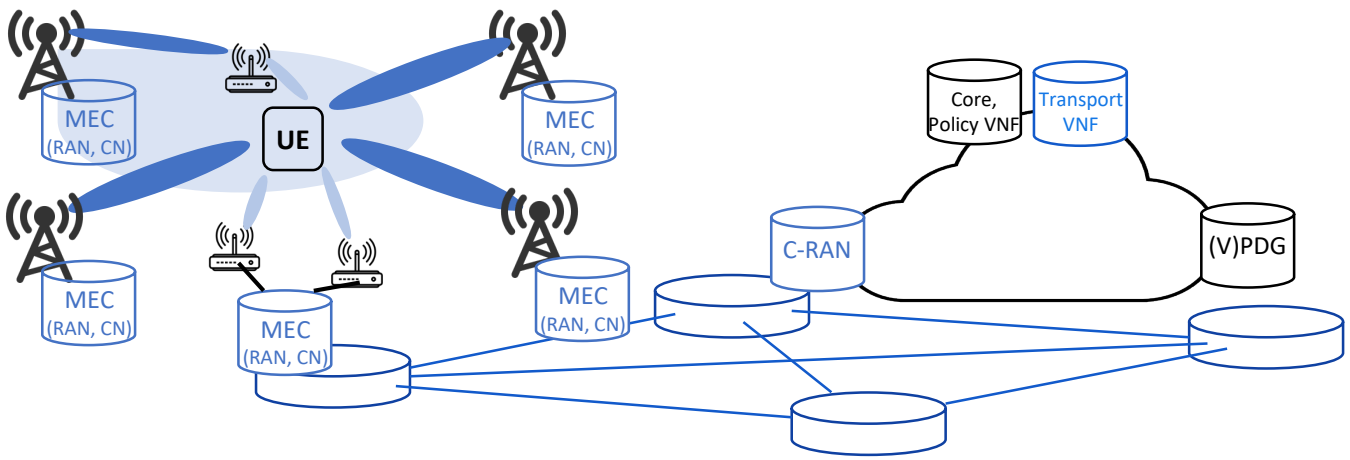
Seamless coexistence of different services

High reliability and proven security

1. Low-power, wide-area; 2. Including cellular and LPWA M2M connections, Machina Research, June, 2018

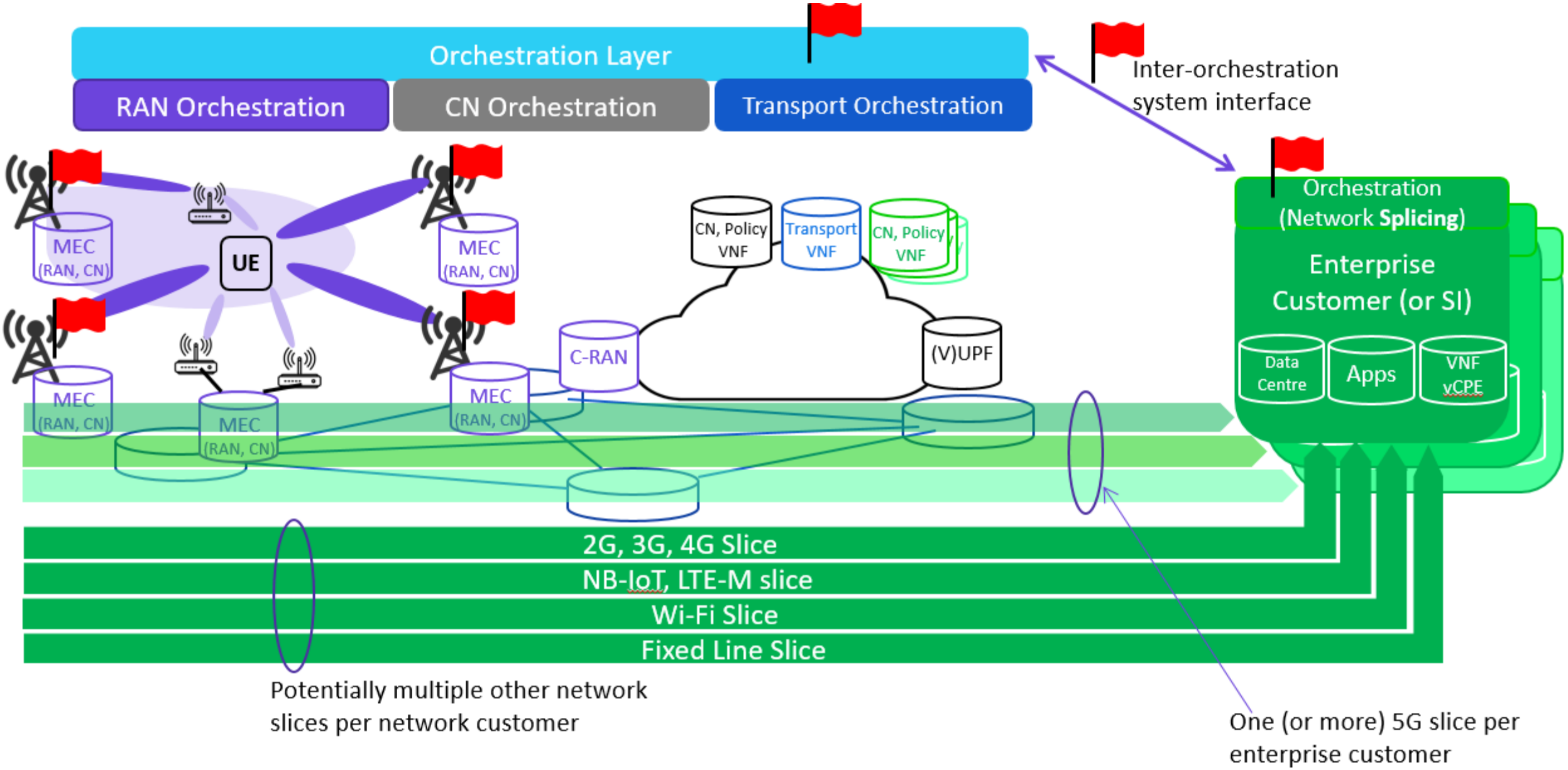

Bluetooth
Bluetooth Mesh
802.11ac
802.11ax
802.11ad
802.11n
802.15.4
NFC
4G/LTE
Powerline
GNSS/Location
Connectivity
Deep learning
Camera processing
Audio processing
Sensor processing
CPU
GPU
DSP
Video processing
Display processing
Power management
Computing
011
100
Security
Secure boot
Secure storage
Key provisioning
Trusted execution environment
Secure debug
Hardware crypto
Wireless protocol security

4G/5G Topology flexibility



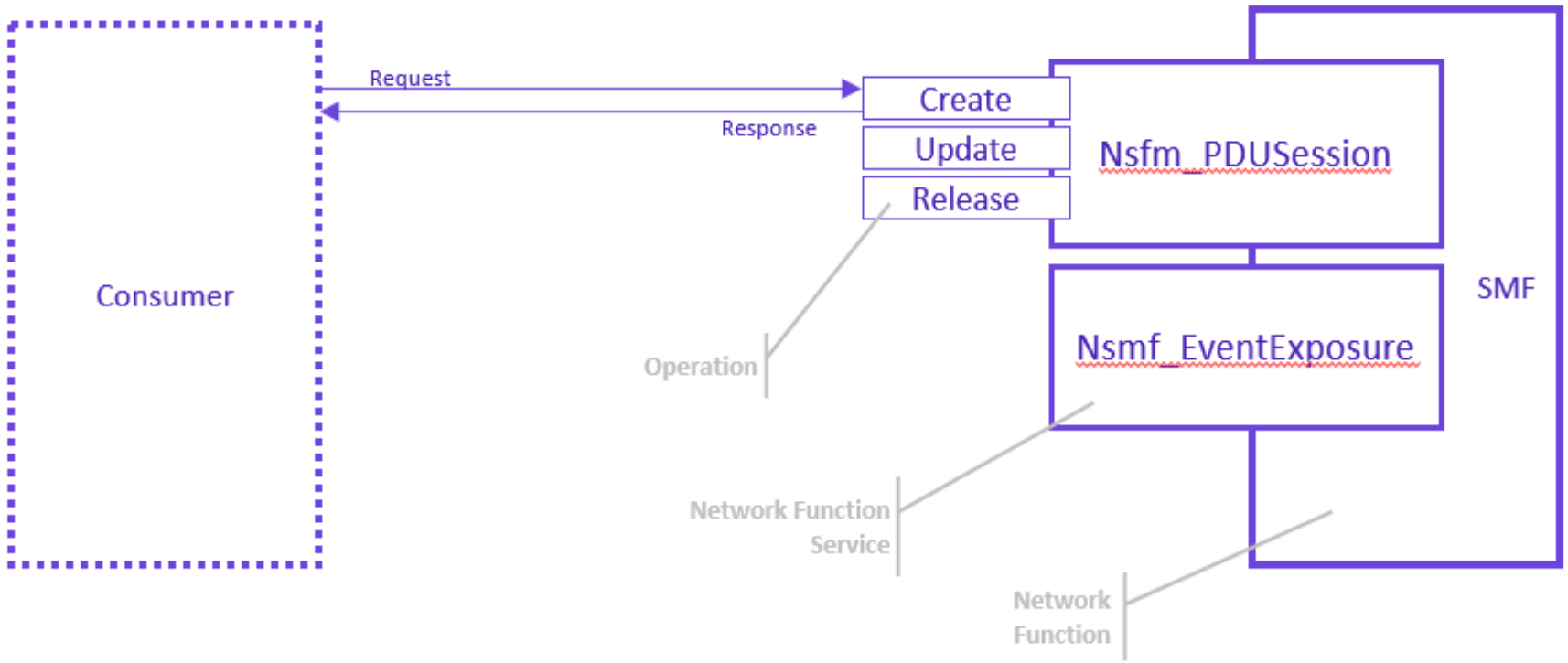
‘Softwarisation’ of the network
C-RAN: removal of functionality from cell sites to consolidation point in the network
NFV and SDN: enabling flexibility in where functions are deployed and scaled
MEC: pushing Core Network functions and content ingress to cell sites
CP/UP split: decoupling of user plane traffic from control plane functions

Network Splicing

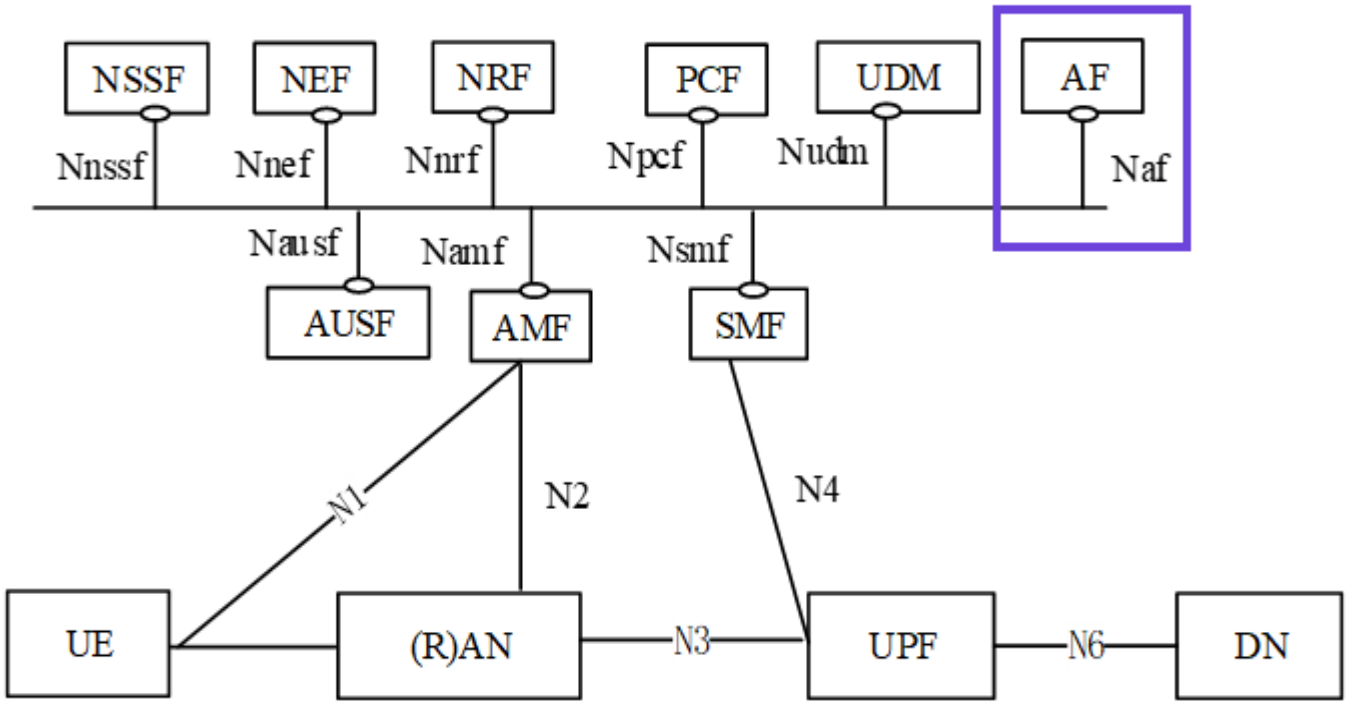


Functions, Services, Operations

- **Each entity in the architecture is (still) called a Network Function**
- **For those entities that are part of the Service Based Architecture**
  - Each of the interfaces to the Network Functions is a Service Based Interface (eg Nsmf)
  - Each Network Function supports one or more Network Function Services exposed via its Service Based Interface
  - Each Network Function Service supports one or more Operations
- **Operations can be invoked by other entities (Consumers)**



AF with http2 interface



- **The Application Function (AF) can be a mutually authenticated third party.**
  - Could be a specific 3rd party with a direct http2 interface or a interworking gateway exposing alternative API's to external applications.
- **Enables applications to directly control Policy (reserve network resource, enforce SLAs), create network Slices, learn device capabilities and adapt service accordingly, invoke other VNF's within the network…**
- **Can also subscribe to events and have direct understanding of how the network behaves in relation to the service delivered.**

- **Because the SBA is made up of VNFs, the AF could be deployed on a MEC server, in a network Cloud, on dedicated hardware. It could be dynamically brought into the network, or a specific network slice, and then removed when no longer in use.**

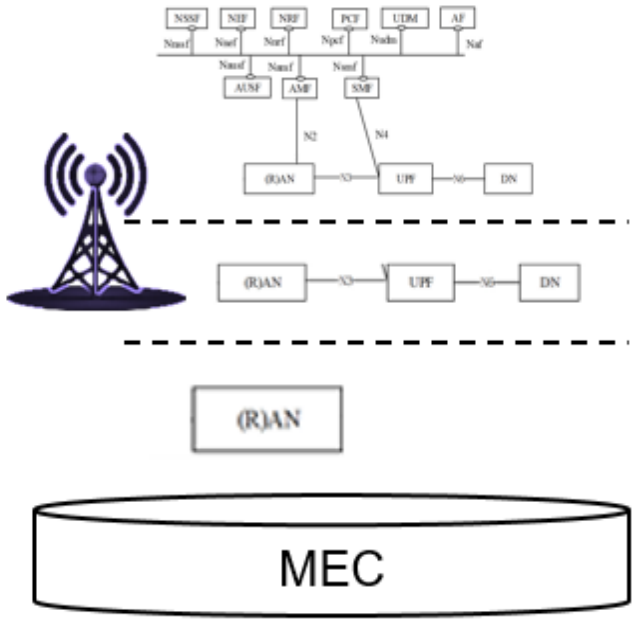
APIs and Network Orchestration COTS

APIs

App, Dev, Web communities

API(s)

Orchestration



NSSF NEF NRF PCF UDM AF

Nnssf Nnef Nnrf Npcf Nudm Naf

Nausf Namf Nsmf

AUSF AMF SMF

N2 N4

(R)AN N3 UPF N6 DN

Core

Conclusions

SBA, and the adoption of http2 is an opportunity for Web, App, Dev communities to access network capabilities

Not all networks will be 5G-SA day 1 (or Day N+1), so there is network-specific perspective to what will be available when and where

3GPP are in the process of defining the interfaces in the SBA architecture so there is an opportunity to work with the telecoms ecosystem to get this right

3GPP takes a looooong time, and adoption may take even longer – will web community wait? (You haven't in the past, particularly when device APIs get the job done)

URLLC and Massive IoT are the target use cases for 5G

eMBB is where initial launches will be targeted.

B2B, B2B2C business models drive 5G business case

No one actually knows what the business case is yet, and B2B, B2B2C come with different expectations from the customer around SLA, KPI and contractual penalties, liability

Set aside the radio – an SBA 5G Core network, with softwarisation, virtualisation, orchestration, MEC and slicing is going to take operators a while to get their heads around.

Consequences

- 1 ms latency for AR, VR, remote surgery is pointless without a video codec that runs significantly faster than 1000 frames per second
- TCP/IP is not fit for purpose. Packet loss handling will break a lot of 5G use cases
- Neither is GTP. Internet of Things needs ‘Internet to the Thing’ without a proprietary connectivity network in the way
- Wireless Networks have had to wait for common hardware platform performance to reach current performance and availability requirements before NFV/SDN could happen. 5G performance and availability requirements are an order of magnitude harder and pushing the platform down in to a more remote part of the network
- Driverless autonomous cars are great, as long as they are all autonomous. There is a massive backward compatibility issue when some cars are driverless and others aren’t
- Existing Roaming model won’t cut it, we have been trying to change Roaming for years. It is not technology that stops it changing.

IPv6 vs. IPv4

Feature	IPv4	IPv6
Deployed	1978	1999
Address format	129.5.255.2/16	2001:0ba0:01e0:d001:0000:0000:d0f0:0010
Address Space	Over 10^9; possible addresses, 32 bit address space	Over 10^{38}; possible addresses. 128 bit address space
Packet Size	Variable size- time consuming to handle	Fixed size (40 Octets) More efficient
Special fields in header	Many types, often not supported by venders .	Eliminated for efficiency or replaced by other features.
Security	-limited: no authentication or encryption at IP level. -Dependence on higher level protocols; vulnerable to **DoS** and address deception or **spoofing** attacks.	-Authentication(validation of packet origin). -Encryption(privacy of contents) -requires administration of “security associations” to handle key distributions.
Quality of Service	-Defined but not generally used, connectionless, best effort delivery,	-Flow labeling -Priority -Support for real-time data and multimedia distribution

eSIM/eUICC

- **eSIM provides an equivalent level of security as the removable SIM card**. This is **vital** as it is the subscription credentials stored on the SIM card that enable secure and private access to mobile networks. It also supports the integrity of the billing process, especially in roaming scenarios:
- **For the device end user,** eSIM enables simplified management of subscriptions and connections. End users will no longer have to manage several SIM cards:
- **For organisations**, eSIM enables remote management of subscriptions. This is a significant benefit where devices are not managed by the end user or are not be readily accessible (for example due to operational scale, making individual device management cost prohibitive). This enables pioneering categories of connected devices:
- **For distributors**, simplified logistics are possible, customisation for specific operators or regions may be reduced:
- **Operators** will have simpler means to expand their businesses into emerging markets, for example, automotive, wearables and consumer electronics. SIM card distribution costs will be eliminated, and eSIMs will enable new distribution models for devices and for marketing of subscriptions:
- **Device Manufacturers**, can exploit the reduced space within their products to make smaller devices. Their products could also be made more tolerant to environmental factors such as dampness, temperature and vibration as they can be hermetically (completely airtight) sealed. Manufacturers can also leverage eSIMs to optimise supply chain processes.

Mobile Security Architecture, an Example

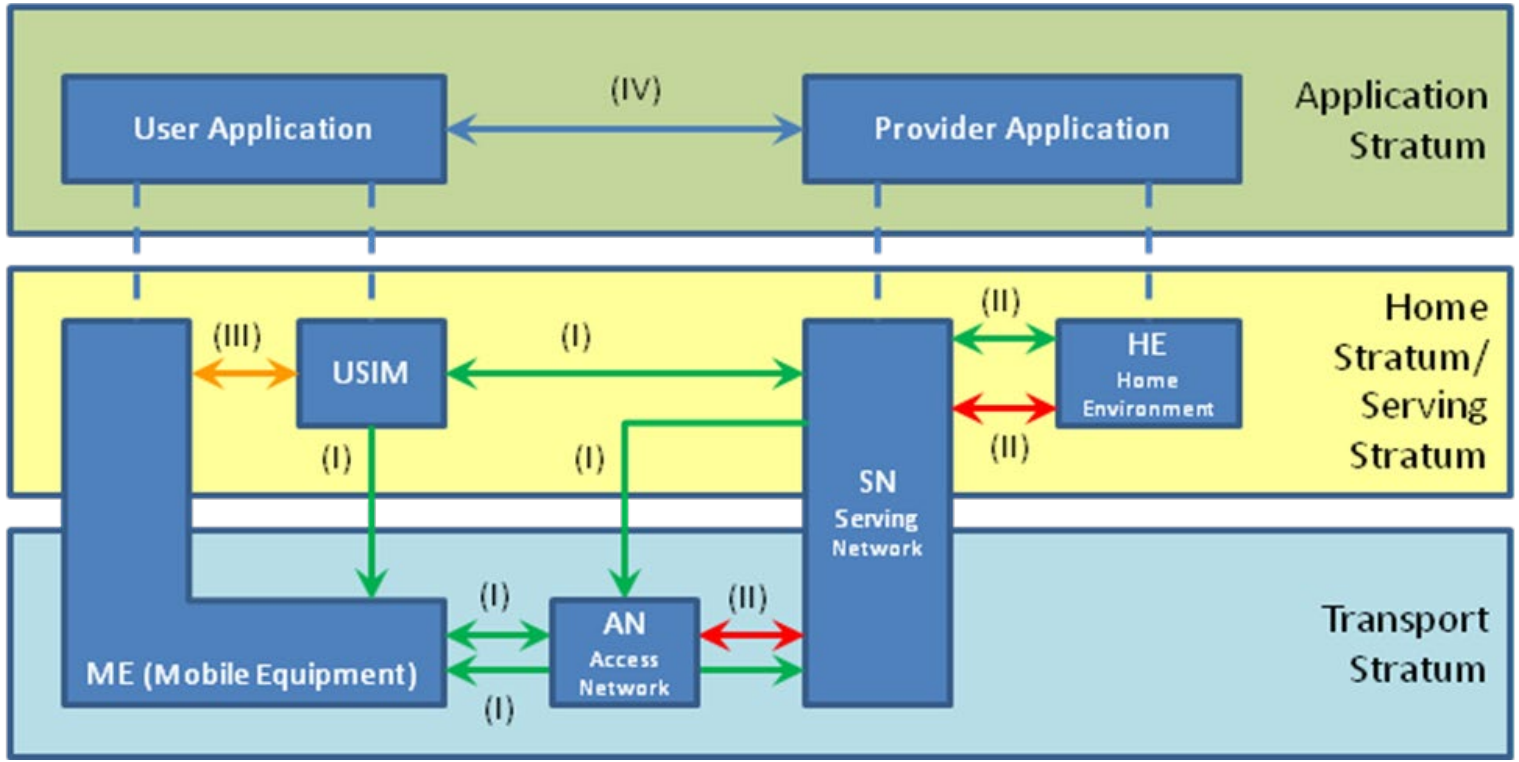
(I) Network Access Security – The set of security features that provide users with secure access to services, and which inparticular protect against attacks on the (radio) access link.

(II) Network Domain Security – The set of security features that enable nodes to securely exchange signaling data, user data (between AN and SN and within AN), and protect against attacks on the wire line network.

(III) User Domain Security – The set of security features that secure access to mobile stations

(IV) Application Domain Security – The set of security features that enable applications in the user and in the provider domain to securely exchange messages.

(V) Visibility and Configurability of Security – The set of features that enables the user to determine whether a security feature is in operation or not and whether the use and provision of services should depend on the security feature



5G Interfaces

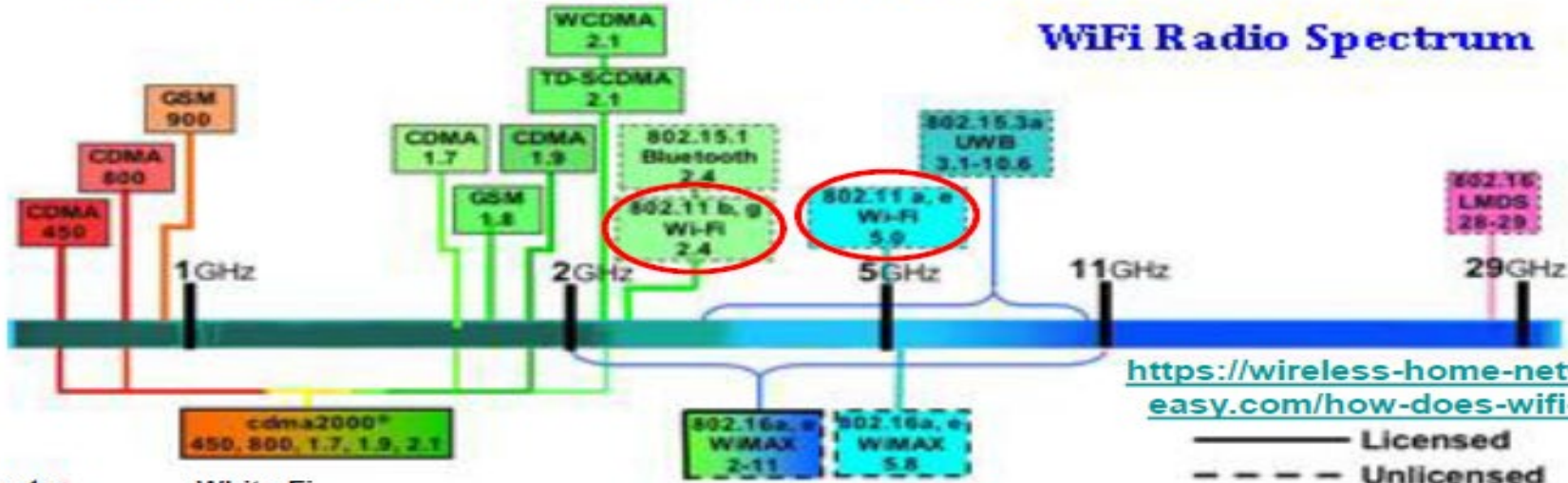
- N1: Reference point between the UE and the Access and Mobility Management function (AMF).
- N2: Reference point between the (R)AN and the Access and Mobility Management function.
- N3: Reference point between the (R)AN and the User plane function (UPF).
- N4: Reference point between the Session Management function (SMF) and the User plane function (UPF).
- N5: Reference point between the Policy Function (PCF) and an Application Function (AF).
- N6: Reference point between the UP function (UPF) and a Data Network (DN).
- N7: Reference point between the Session Management function (SMF) and the Policy Control function (PCF).
- N7r: Reference point between the vPCF and the hPCF.
- N8: Reference point between Unified Data Management and AMF.
- N9: Reference point between two Core User plane functions (UPFs).
- N10: Reference point between UDM and SMF.
- N11: Reference point between Access and Mobility Management function (AMF) and Session Management function (SMF).
- N12: Reference point between Access and Mobility Management function (AMF) and Authentication Server function (AUSF).
- N13: Reference point between UDM and Authentication Server function (AUSF).
- N14: Reference point between 2 Access and Mobility Management function (AMF).
- N15: Reference point between the PCF and the AMF in case of non-roaming scenario, V-PCF and AMF in case of roaming scenario.
- N16: Reference point between two SMFs, (in roaming case between V-SMF and the H-SMF).
- N22: Reference point between AMF and Network Slice Selection Function (NSSF).

ABBREVIATIONS

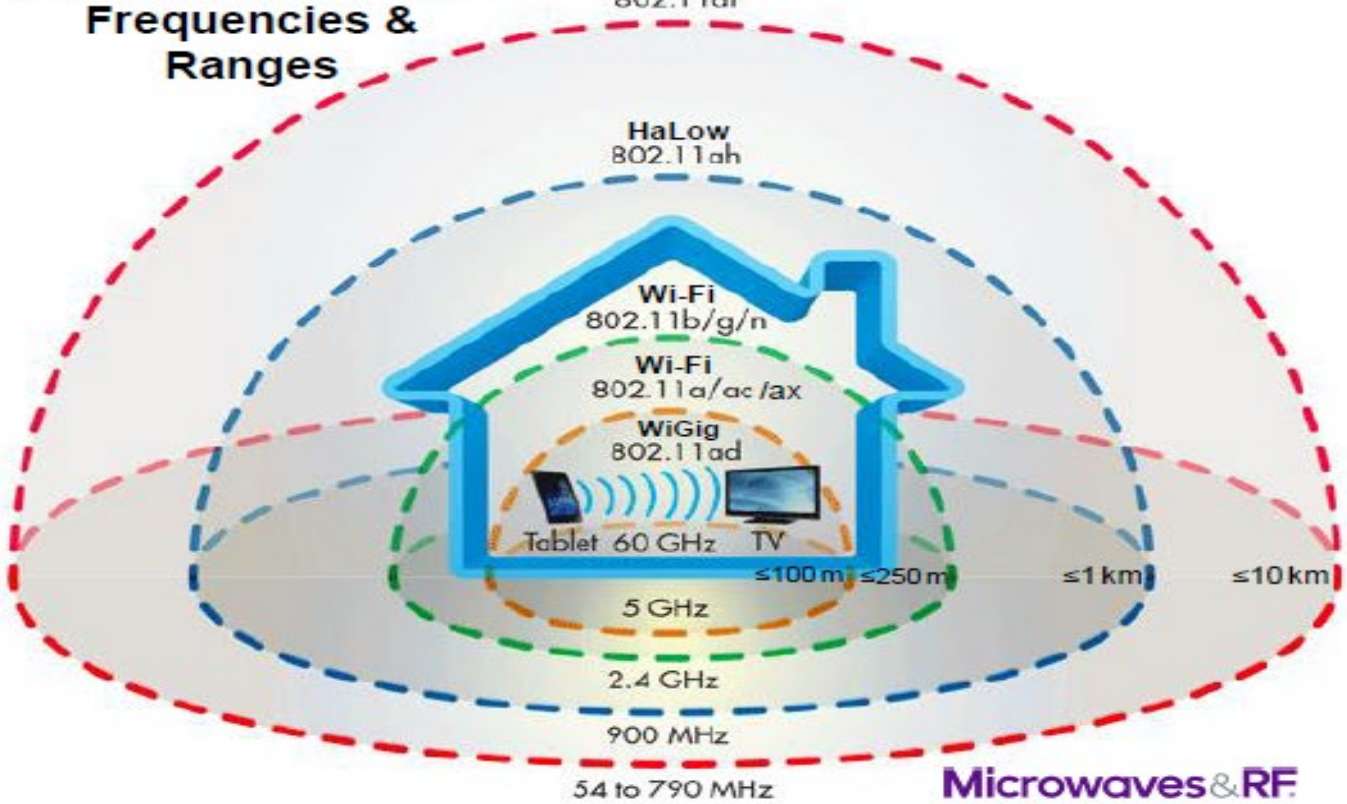
3GPP	3rd Generation Partnership Project
AAU	Active Antenna Unit
AF	Application Function
AMF	Access and Mobility management Function
ARQ	Automatic Repeat request
AUSF	Authentication Server Function
BBU	BaseBand Unit
CP-OFDM	Cyclic Prefix-Orthogonal Frequency Division Multiplex
CPRI	Evolved CPRI
CU	Centralised Unit
DN	Data Network
DU	Distributed Unit
eCPRI	Evolved CPRI
eMBB	Enhanced Mobile Broadband
EPC	Evolved Packet Core
FDD	Frequency Division Duplex
gNB	next Generation Node B
gNB-CU	gNB-Centralised Unit
gNB-DU	gNB-Distributed Unit
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
mMTC	Massive Machine Type Communications
NEF	Network Exposure Function
NGC	Next Generation Core
NR	New Radio
NRF	Network Repository Function
NSA	Non-Standalone
NSSF	Network Slice Selection Function
PCF	Policy Control Function
PDCP	Packet Data Convergence Protocol
QoS	Quality of Service
RAN	Radio Access Network
RLC	Radio Link Control
RRC	Radio Resource Control
RRU	Remote Radio Unit
SBA	Service Based Architecture
SDAP	Service Data Adaptation Protocol
SMF	Session Management Function
TDD	Time Division Duplex
TNL	Transport Network Layer
UDM	Unified Data Management
UE	User Equipment

THANK YOU

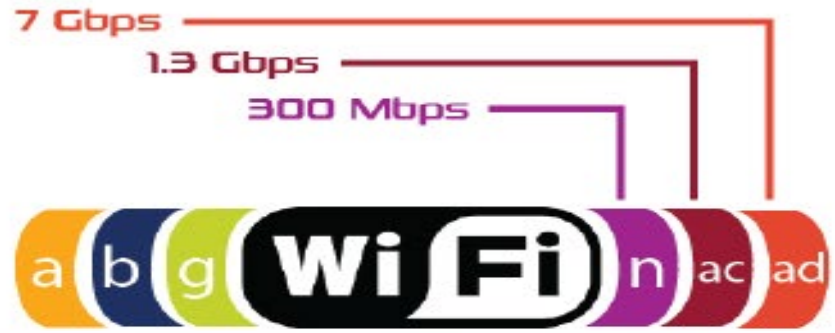
IEEE 802.11 Wi-Fi Wireless Overview



IEEE 802.11 Variants, Frequencies & Ranges



Current Wi-Fi LAN/WAN Characteristics



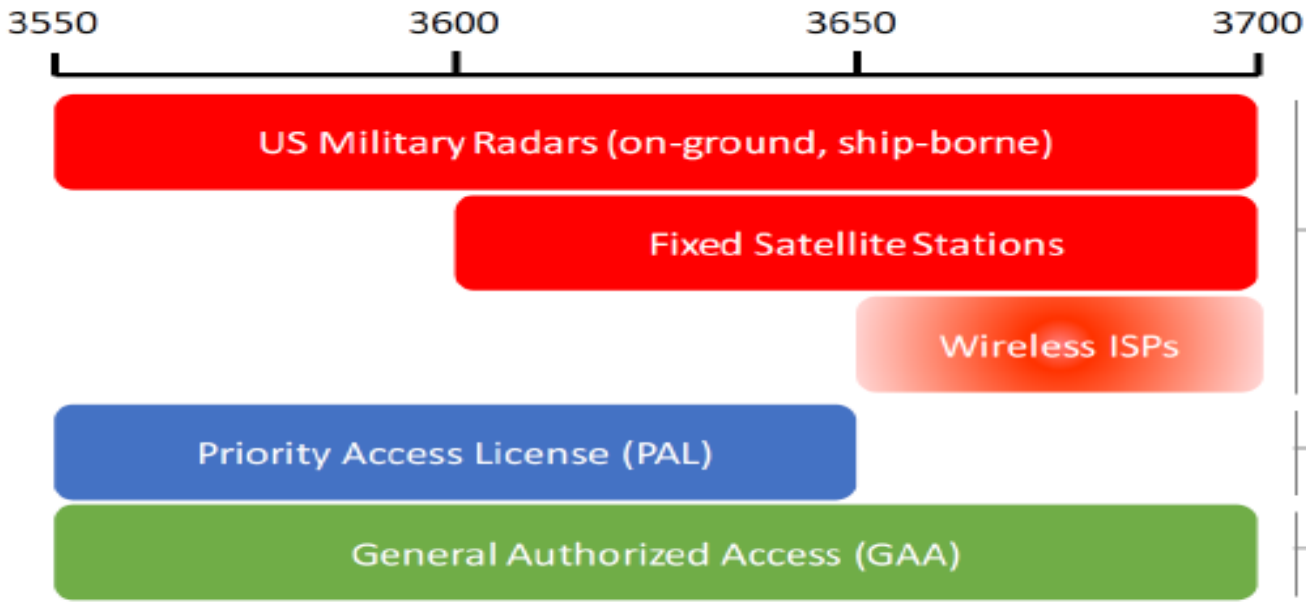
	802.11n	802.11ac	802.11ad
Throughput	600 Mbps	3.2 Gbps	Up to 7 Gbps
Coverage	Home, 70 m	Home, 30 m	Room, <5m
Freq. Band	2.4/5 GHz	5 GHz	2.4/5/60 GHz
Antennas	4 x 4 MIMO	8 x 8 MIMO	>10 x 10 MIMO
Applications	Data, Video	Video	Uncompressed Video

IEEE 802.11 Wireless Evolution & Outlook

IEEE 802.11 Variant	Tech & Spectrum	Apps & Notes
IEEE 802.11abg Wi-Fi	Legacy protocols on unlicensed 2.4 & 5 GHz bands to 600 Mbps to 100+ m outdoors	Baseline Wi-Fi capabilities for APs & CPE, Overall Wi-Fi performance may be limited by legacy devices & interference
IEEE 802.11n Wi-Fi 4	Adds MIMO streams to abg for focusing transmissions to 250 m	Great advance in Wi-Fi performance for multi-antenna APs & CPE
IEEE 802.11ac Wi-Fi 5	Current highest performance protocol on unlicensed 2.4 & 5 GHz bands up to 3.5 Gbps	Downlink MU-MIMO, Mature, widely available advanced Wi-Fi performance & capabilities in base stations, APs & CPE
IEEE 802.11ax Wi-Fi 6	Pending higher performance protocol on unlicensed 2.4 & 5 GHz bands up to 10.5 Gbps	Wi-Fi 6 spec pending with commercial development & deployment to follow, Full MU-MIMO, OFDMA, WPA3 security
Next Gen Wi-Fi	6 GHZ band unlicensed & cellular reallocation possible	IEEE 802.11k/v/r agile multiband pending, Extreme High-Throughput (EHT) pending
IEEE 802.11p V2X	Unlicensed 5.9 GHz ITS for short-to-medium range, Next gen DSRC	Vehicle-to-Vehicle (V2V) & Vehicle-to-Everything (V2X) for vehicle safety & ops
IEEE 802.11af White Spaces White-Fi	Uses select unlicensed TV bands from approx. 470-700 MHz to 600 Mbps up to 10 km (long distance) NLOS, Nominal cost for geo database use per device	White-Fi, White Spaces Wireless or Super Wi-Fi, Managed by cognitive radio tech & geo database dynamically assigning channels for use, IEEE 802.22 emerging for WRAN up to 100 km
IEEE 802.11ah HaLow	Uses unlicensed 902-928 MHz UHF frequencies up to 100 Kbps to 1 km, up to 8K low power devices per AP	WWAN supporting bulk M2M & Io/IIoTT communications for long-range, low-data rate applications
IEEE 802.11ad WiGig	Uses unlicensed 60 GHz ISM band for up to 7 Gbps up to 5 m range (within a room)	Optimized for short-range media & high-bandwidth apps, IEEE 802.11ay will eventually extend to 20+ Gbps

Source: International Research Center

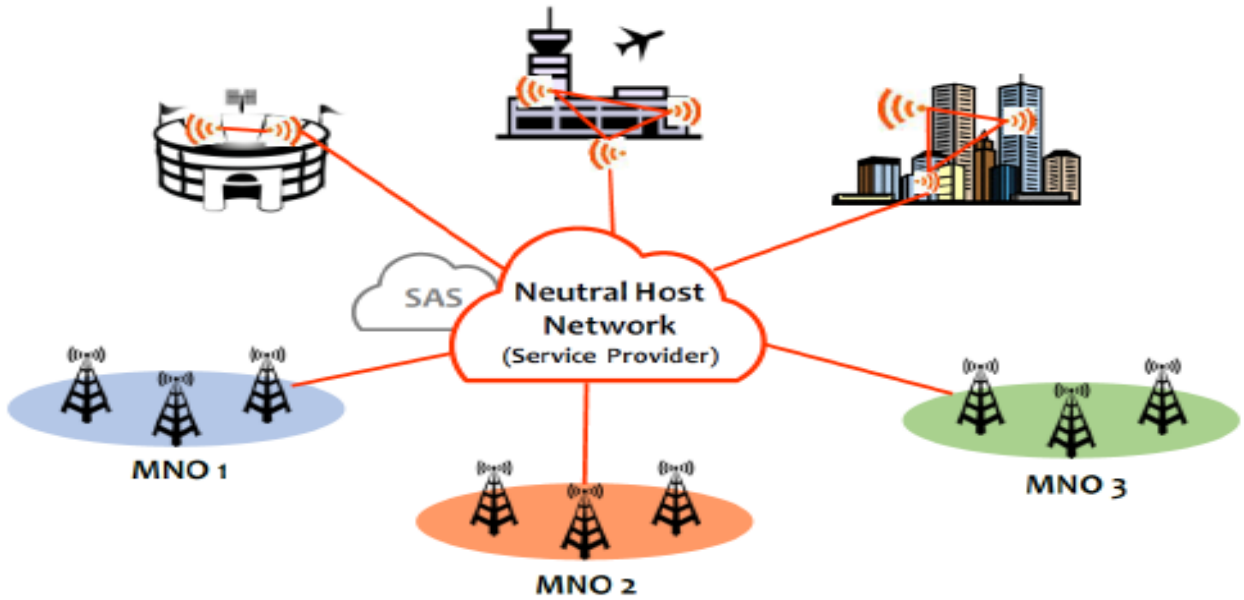
Citizens Broadband Radio Service (CBRS) Wireless Spectrum: Frequencies & Tiers



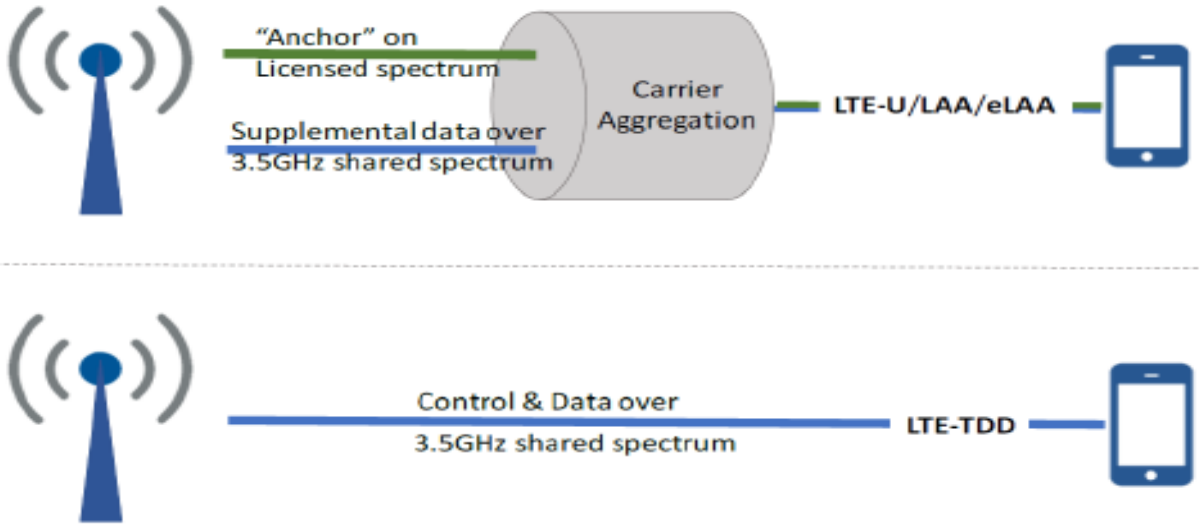
Spectrum Type:	Licensed	Unlicensed	CBRS
Licnse Rights	Exclusive	Non-Exclusive	"Use it or Share it"
Licnse Area	Large, contiguous metro areas (MSAs)	N/A	Calculated in real-time based on exact location (±50m H,±3m V) and comprehensive RF propagation models
Licnse Cost	$Billions in auctions	Free	Free with monthly fee for SAS. Option for additional local protection (PAL) for a fee at auction.
Enforcement	Legal/Regulatory	Power limits, LBT	Central coordination service (SAS) (SAS = Spectrum Allocation Server)
Technologies	GSM, CDMA, LTE	Wifi, BT, MulteFire	LTE https://www.leverege.com/blogpost/what-is-cbrs-lte-3-5-ghz
Deployed by	MNOs	Anyone	Enterprises, MSOs, MNIOs, or MSPs

Citizens Broadband Radio Service (CBRS) Wireless Opportunities

Neutral Host Network Provider with OnGo



Neutral Host Network Provider with OnGo



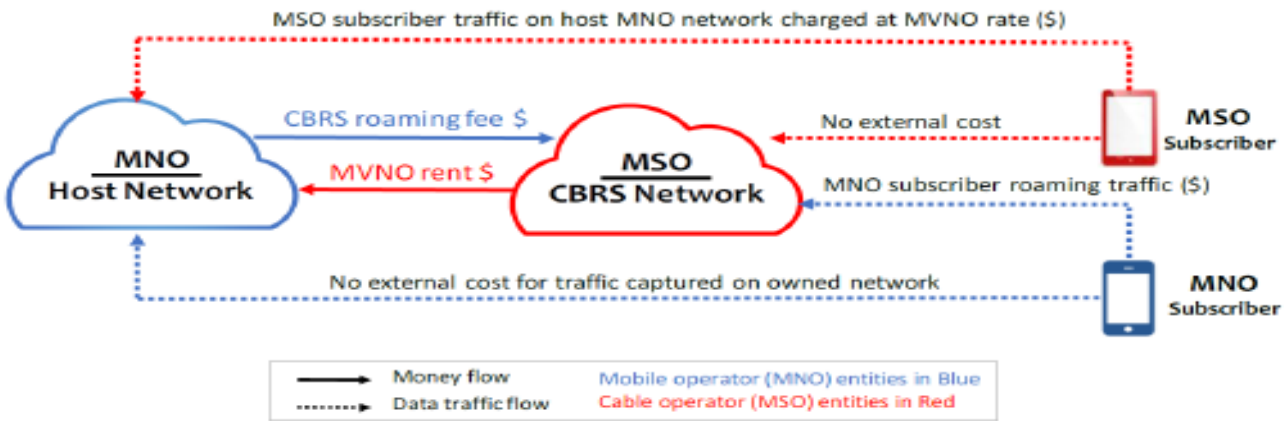
CBRS Alliance's OnGo (https://www.cbrsalliance.org/) improves wireless coverage and capacity on a massive scale, making it ideal for in-building, public space and IoT/IIoT wireless needs

ALLIANCE cbrs
Shared spectrum. Expanded opportunities.
OnGo

MulteFire Alliance (https://www.multefire.org/) combines the high performance of LTE with the simple deployment of Wi-Fi

MULTEFIRE

New Entrant MVNO Capacity Improvement Business Model



Graphics: Mobile Experts
https://www.mobile-experts.net/